

Environmental Effects on High-Frequency Seafloor Scattering Statistics

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LONG-TERM GOALS

The long-term goals of this research program are to determine and characterize the causes of clutter in the output of high-frequency sonar systems operating in shallow water areas that have spatially heterogeneous seafloors and to link a statistical characterization of returns to the environment through models.

OBJECTIVES

Future mine-hunting sonars will be higher in frequency and broadband and therefore much higher in resolution. Heavy-tailed scattered amplitude distribution functions (acoustic clutter) will be one of the primary factors limiting the performance of these types of MCM hunting and classification sonar systems in shallow water.

The specific objectives of this project are:

1. Through analysis of experimental data and modeling, determine the primary causes of clutter observed in high-frequency sonar systems in shallow water.
2. Develop methods for characterizing, modeling and predicting the effects of clutter on current and future MCM systems.
3. Define an adaptive strategy to a given environment for mitigating the effects of clutter on mine hunting systems.

APPROACH

The objectives of this project are being achieved through a combination of at-sea measurements and modeling primarily at frequencies between 30 and 300 kHz. Data sets consist of high-frequency oblique incidence acoustic measurement taken during various high-frequency SACLANT Undersea Research Centre (SACLANTCEN) experiments as well as during the MAPLE multi-sensor fusion experiment (Chief Scientists: E. Pouliquen and M. Trevor) which was part of a Joint Research Project (JRP) between SACLANTCEN and Defense Research and Development Canada (DRDC) that took place in June 2001. Ground truth for the high-frequency scattered amplitude variability component of this experiment consisted of a combination of digital seafloor stereo photography, high-resolution side scan sonar records and sediment grab samples, which are being examined to determine

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the causes of non-Rayleigh reverberation at high frequency and where possible to quantitatively estimate the heterogeneity of seafloor properties, e.g., patch sizes, composition, etc.

The data from these experiments are providing initial images and data for forming and testing hypotheses on the causes of clutter, for characterizing and formulating a connection with environmental factors (geological/biological patchiness) and for exploring the dependence of clutter on system characteristics such as frequency, incidence angle or pulse length. A variety of areas with more complicated bottom properties such as with shellfish, sea grass, or rocks, were found during the experiment. The diversity of sites studied allows an excellent opportunity to examine the statistics of scattering from a wide variety of extreme seafloor environments in terms of acoustic clutter.

WORK COMPLETED

An initial background study and examination of bottom photographs of heterogeneous seafloors taken during the SACLANTCEN/DRDC(CA) JRP experiment has been undertaken to determine the various causes of non-Rayleigh envelope distributions (clutter) in shallow water. High-frequency (80 kHz) acoustic data taken during the 1996 SACLANTCEN Rapid Response experiment (reported in Lyons and Abraham, 1999) has been revisited to determine angular changes in the scattering statistics that might arise from the scattering physics. From these two data sets it has been determined that a plausible cause of non-Rayleigh amplitude distributions is the patchiness in seafloor scattering properties often found in shallow water areas.

In collaboration with Douglas A. Abraham, a predictive model for the statistical distribution of the envelope resulting from scattering from two different contributing seafloor types within the same resolution cell has been developed. The seafloor was modeled as being comprised of a finite number of homogeneous exponentially sized scattering patches (in contrast to the more traditional asymptotic derivation of the K-distribution) on a background (the area around the scattering patches) that was assumed to produce a Gaussian scattered return. The patch-scattering model which links environmental parameters to the final statistical distributions has been favorably compared to the high-frequency Rapid Response acoustic data described above. Sample results of this model are presented in the next section.

Also underway are initial discussions with SACLANTCEN on the design of a high-frequency scattering statistics experiment planned for spring 2003 as part of a SACLANTCEN/ARL-PSU Joint Research Project and with APL/UW on incorporating a statistical component into the 2004 follow-on experiment to the 1999 SAX99 high-frequency acoustic scattering experiment.

RESULTS

Local hydrodynamic or biological influences often produce seafloors in shallow water that consist of differing types of material. The scattering properties from the components of these kinds of seafloors may have a complicated relationship in terms of their frequency dependence and/or angular response. Consequently, this relationship directly influences the angular and frequency response of the scattered envelope distributions. The probability distribution function (PDF) for a scattering scenario such as this is not easy to obtain analytically. However, a recently developed model for a patchy seafloor with a single dominating component (Abraham and Lyons, accepted for publication in IEEE J. Ocean. Eng.) allows for numerical analysis of the envelope PDF for more complicated seafloors through the use of

Hankel transforms of the joint characteristic function (JCF) of the complex envelope. The JCF is straightforward to construct for complicated patchy seafloors.

Scintillation index (variance of intensity fluctuations) estimated from high-frequency acoustic scattering data (Figure 1) were compared with scintillation index predictions (Figure 2) made using the developed patch-scattering model and realistic input parameters for several example seafloor descriptions. The predicted scintillation index compared quite favorably with the level and angular dependence of experimental data. The strong peak seen in both the experimental and predicted scintillation index near normal incidence resulted solely from the angular dependence of the relative scattering strengths of the two contributing seafloor types within a resolution cell.

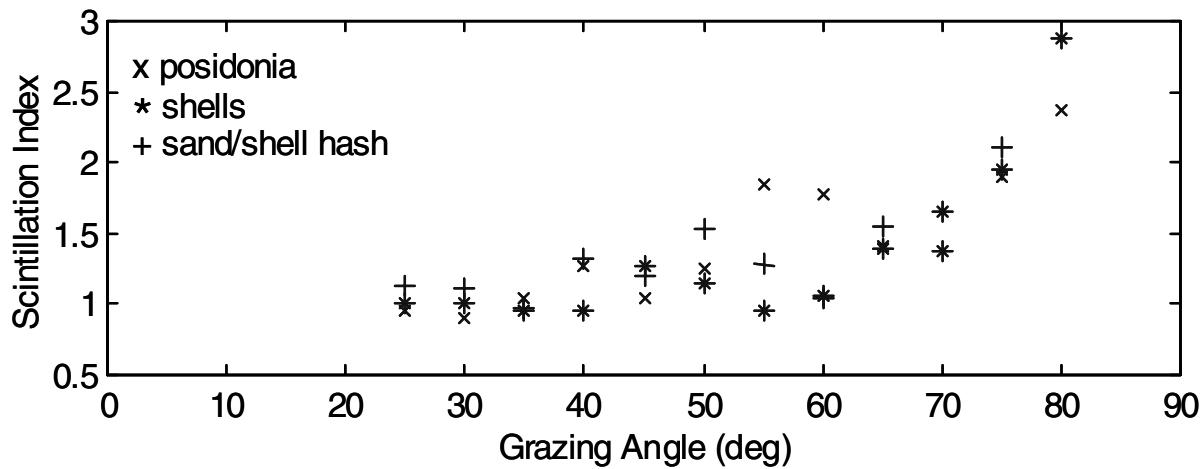


Figure 1. Experimental values of scintillation index versus grazing angle from 80 kHz acoustic backscattering data taken from Lyons and Abraham, 1999.

The importance of these results lies in the ability to link the clutter envelope distribution to measurable geo-acoustic properties in conjunction with sonar system parameters, providing the foundation necessary for solving several important problems related to the detection of targets in non-Rayleigh clutter. The direct link between system and environmental parameters and the statistical distribution of reverberation will allow: performance prediction for different systems based on seafloor properties, extrapolation of performance to other system/bandwidths, and optimization of system parameters such as bandwidth to local environment.

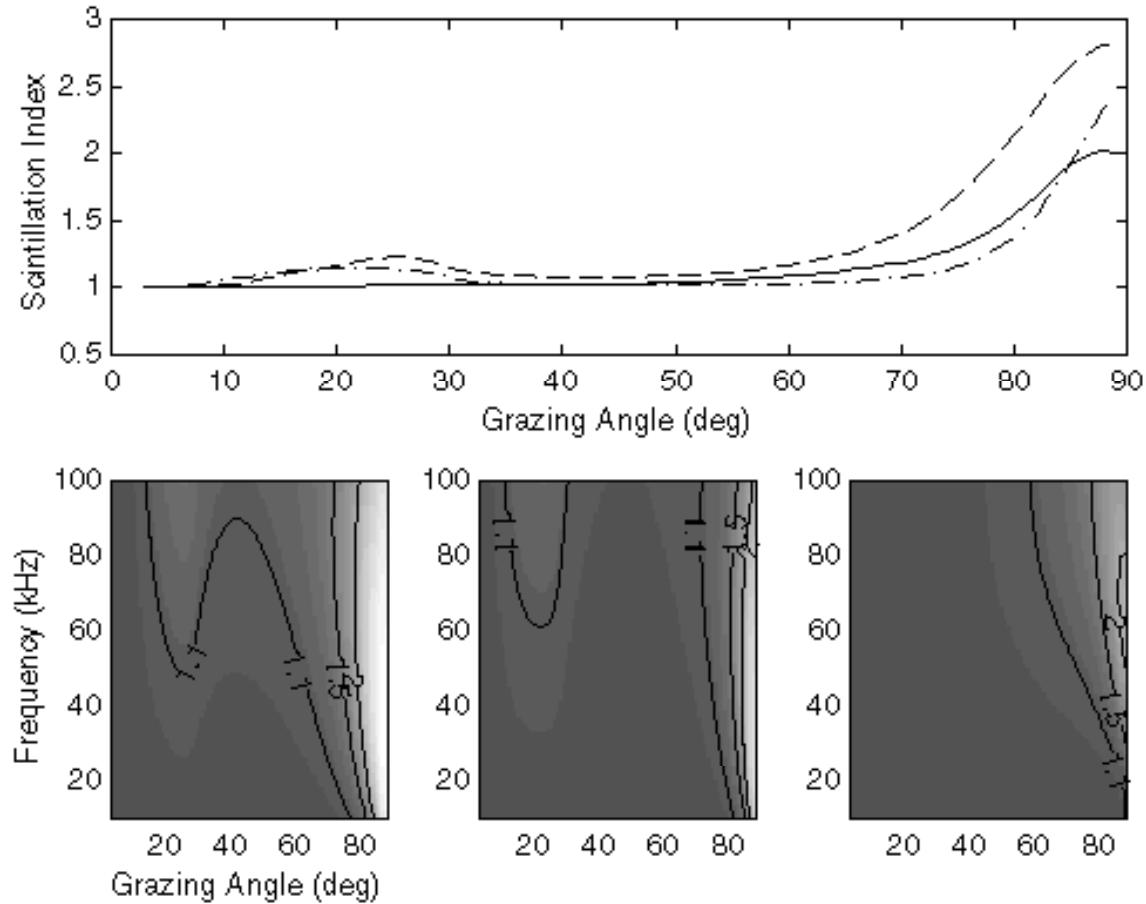


Figure 2. *Top: Predictions of 80 kHz scintillation index versus grazing angle for sand patches on: shell-covered (dash-dot line), gravel (solid line), and seagrass-covered (dashed line) seafloors. Bottom: Scintillation index versus grazing angle and frequency for sand patches on: seagrass-covered (left), shell-covered (middle), and gravel (right) seafloors. Larger values are lighter on these plots and contour lines of 1.1, 1.5 and 2 are also shown.*

IMPACT/APPLICATIONS

This research is providing an improved understanding of the link between environmental parameters and system factors in causing clutter, as well as models and methods for characterizing, predicting and mitigating clutter. This study is leading to methods for modeling and predicting acoustic clutter that may be used to minimize the negative impact of clutter on detection and classification of targets on or near the seafloor in shallow water. Knowledge gained will help in the development of reverberation simulation tools, adaptive systems for sonar clutter reduction and methods for rapid environmental assessment techniques for estimating the strength of clutter for a given area.

TRANSITIONS

The statistical models of clutter that have been explored and developed over the past year are being incorporated into the Technology Requirements Model (TRM), a high fidelity, physics-based digital simulator for evaluating dynamic engagements and torpedo defense studies. A compound model,

namely the K-distribution, which has had success in the modeling of radar clutter and sonar reverberation at a variety of frequencies and scales, is being implemented as a statistical model for clutter. Additionally, a more generic model, (based on the results of the project reported in this annual report) which links a physical description of the environment (e.g., densities of scatterers, clustering of scatterers, scattering strength of scatterers, etc.) to scattering statistics via K-distribution parameters is being examined for inclusion into TRM. This relationship will allow efficient simulation of false alarms and false targets for many different scenarios for which experimental data do not exist.

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